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Phytosociological changes in understory vegetation following timber harvest in northern Minnesota

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Impacts on the understory of a balsam fir (*Abies balsamea* (L.) Mill.) – paper birch (*Betula papyrifera* Marsh.) stand, caused by winter and spring full-tree logging and by winter tree-length logging which was followed by summer burning, were monitored for two growing seasons after overstory harvest. New species invaded full-tree logging sites, while compositional changes on the burned area were due primarily to the disappearance of species. Prescribed burning on the tree-length logging area prevented the quick increase in density of woody species that occurred on full-tree harvested sites. However, understory production increased on all sites, and by the end of the second season aboveground biomass was 3847, 4516, and 2604 kg/ha on the winter full-tree, spring full-tree, and winter tree-length plus burning sites, respectively, compared with 942 kg/ha on the uncut control.

The major factors causing differences were prescribed burning and snow cover during harvest operations. Since our results concur with previous findings and appear predictable, resource managers can choose the technique best suited to specific objectives. However, no matter which system is used, the same core species will persist afterward, and if succession is allowed to continue, an understory will develop similar to that existing before harvest.

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Les impacts d'une exploitation hivernale et printannière par arbres entiers, suivie par une exploitation en bois long hivernale à laquelle s'ajouta un brûlage d'été, ont été observés sur le sous-bois d'un peuplement de sapin baumier (*Abies balsamea* (L.) Mill.) et de bouleau à papier (*Betula papyrifera* Marsh.) pendant deux saisons de croissance après la récolte du couvert forestier. De nouvelles espèces ont envahi les stations de l'exploitation par arbre entier tandis que les changements dans la composition de la végétation dans l'aire brûlée, résultaient principalement de la disparition de certaines espèces. Le brûlage dans les aires exploitées en bois longs a empêché une augmentation rapide de la densité en espèces ligneuses telle qu'elle s'est produite dans les stations où l'on a exploité par arbre entier. Cependant, la production de sous-bois a augmenté dans toutes les stations, et à la fin de la seconde saison, la biomasse au-dessus du sol atteignait 3847, 4516 et 2604 kg/ha pour les stations de coupe par arbre entier hivernale, par arbre entier au printemps et par bois longs hivernal suivi de brûlage, comparés à 942 kg/ha dans les stations de contrôle.

Les principaux facteurs qui sont la cause de ces différences sont le brûlage et le couvert de neige durant les exploitations. Étant donné que nos résultats confirment de précédentes recherches et semblent prévisibles, les aménagistes de ressources peuvent donc choisir la technique la mieux adaptée à des objectifs spécifiques. Cependant, quelque soit le système employé, le même groupe d'espèces persistera par la suite, et si la succession se poursuit suffisamment longtemps, un sous-bois semblable à celui existant auparavant se rétablira.

[Traduit par le journal]

Changes in understory vegetation after timber harvesting and prescribed burning have been investigated by a number of workers. Although there are some similarities in the phytosociological changes that occur, as shown by studies within the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) regions of Washington and Oregon (Yerkes 1960; Morris 1970; Dyrness 1973) and the Rocky Mountains (Lyon 1971), and the boreal forest region of Ontario (Sidhu 1973, 1974), there is variation between regions and often between communities. Thus, in order to develop sound management practices, it is important to have information for various ecosystem types and locations. The purpose of this study was to assess the effects of timber harvesting and timber harvesting plus prescribed burning on the understory component of a mixed balsam fir (*Abies balsamea* (L.) Mill.) – paper birch (*Betula papyrifera* Marsh.) stand in northern Minnesota. Of particular interest were treatments that would be useful for vegetation management.

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Similar studies were done in the Douglas-fir region of Washington and Oregon to compare the effects of clear-cutting and of clear-cutting followed by slash burning. The amount of herbaceous cover after treatment was similar on burned and unburned areas, but for the first 5 years after treatment there was significantly more woody cover on the unburned sites (Morris 1958, 1970; Steen 1966). Sites that had been clear-cut and burned had fewer species than clearcut areas, but the number of species increased, and after 6 years there was little difference between treatments in numbers of species present (Dyrness 1973). However, a change in species composition was noted: burned areas were dominated by invaders while the residual species, which dominated the unburned sites, were reduced in importance (Yerkes 1960; Dyrness 1973).

Existing evidence suggests that these same trends occur in woody vegetation after clear-cutting in Minnesota forests. Two years after the harvest of jack pine (*Pinus banksiana* Lamb.) stands, the density of shrubs had doubled, going from 61 775 to 123 550 stems per hectare (Alm 1971). Clear-cutting also stimulated root sprouting of quaking aspen (*Populus tremuloides* Michx.) in forests of the region (Maini and Horton 1966).

Study area

The study was done on the University of Minnesota's Cloquet Forestry Center, which is located about 17 km southwest of Duluth, MN (latitude 46°43′ N, longitude 92°29′ W). This area lies within Kuchler's (1964) Great Lakes spruce–fir forest vegetation zone. The climate is subhumid continental, with long, cold winters and short, warm summers. The average temperature is −12.8°C for January and 19.4°C for August (Baker and Strub 1965). The average yearly precipitation is 72.9 cm with a June maximum and a February minimum (Baker *et al.* 1967).

Weather during both years of the study was similar but somewhat abnormal, with below-average precipitation and above-average temperatures during the growing season. The first year, precipitation for the period of April 1 to September 30 was 44.8 cm, 10.3 cm below normal, and for the same period the second year it was 36.3 cm or 18.8 cm below normal. June, however, had above normal precipitation both years; 17.3 cm or 5.8 cm above normal the first year, and 18.0 cm or 6.5 cm above normal the second.

The study site was part of an area which had been logged in 1910 (Shannon 1976). The stand that occupied the site before the study was predominately balsam fir and paper birch, with scattered red maple (*Acer rubrum* L.), quaking aspen, white spruce (*Picea glauca* (Moench) Voss), and white pine (*Pinus strobus* L.). Total basal area was 19.6 m^2/ha, of which balsam fir constitutes 71% and paper birch 15%. There were 949 trees/ha, 75% of which were balsam fir. Average diameter at breast height (dbh) for both balsam fir and paper birch was 15.7 cm. Site index for balsam fir was 18 m (50-year base age).

The site is located on an outwash plain of Omega loamy sand. This series is classed as a mixed, frigid Spodic Udipsamment, an excessively drained soil with low moisture holding capacity and organic matter content (Soil Conservation Service 1978). It has an acid solum with pH ranging from 4.5 to 5.5.

The site was divided into three cutting areas of about 0.8 ha each and an uncut control of about 0.6 ha. The treatments were full-tree logging and tree-length logging with a protective snow cover (winter 1974–1975), and full-tree logging without snow cover (spring 1975). In the full-tree logging system, trees are felled and skidded intact to a landing for processing while in the tree-length system, trees are felled, limbed and topped on site, and then the bole is skidded to the landing (Zasada 1971). The logging operation was a total clearcut with all stems larger than 2.54 cm dbh felled. The unmerchantable stems were left in place on the sites.

The tree-length site was prescribed burned in July 1975. The fire had a high buildup index of "26"; this is a measure of fuel dryness (Nelson 1964). When the burn was started, the humidity was 45%, temperature 31°C, and the wind from the southwest at 19 km/h with gusts up to 48 km/h.[4]

[4]Personal communication with Dr. A. Alm, University of Minnesota, Cloquet Forestry Center, Cloquet, MN.

Methods

Ten circular 4.0-m^2 plots were located in each of the three harvest areas and the control. Just before logging operations were begun a list of understory species was compiled from these plots. The understory was defined as herbaceous plants plus all woody stems less than 2.54 cm dbh. The following growing season 10 additional plots were established on each area using a stratified random system. The number of individual plants were recorded, by species, for each of the 20 plots on a site. The same plots were surveyed in July of the first and second growing seasons following harvest on all but the burned site, which was not measured the first season owing to a lack of sufficient vegetation.

At the end of each growing season, all aboveground understory vegetation was clipped and collected from ten 0.88-m^2 randomly selected circular plots within each area. The first-year samples were separated into herbaceous and woody vegetation by plot. The second year, the major species were collected separately by plot and the minor species were bulked. All vegetation collected was oven-dried at 65°C.

Density and biomass data for species were grouped on the basis of structural similarities: ferns and fern allies, grasses, vines, low herbs, tall herbs (annuals and biennials), tall herbs (perennials), low shrubs, tall shrubs, and tree reproduction. Low herbs were those that do not grow taller than 30 cm; tall

TABLE 1. Percent frequency of understory species before logging

Species	Treatment: Winter full-tree logging	Spring full-tree logging	Winter tree-length logging and summer burn	Control
Woody species				
Abies balsamea	10	30	30	20
Acer rubrum	10	30	30	30
Acer spicatum	40	30	50	30
Betula papyrifera	10	10	10	10
Corylus cornuta	50	70	50	90
Diervilla lonicera	60	70	70	100
Linnaea borealis	30	60	30	50
Populus tremuloides	10	10	10	10
Rosa spp.	10	10	0	10
Vaccinium spp.	10	0	0	10
Herbaceous species				
Coptis groenlandica	10	0	10	0
Cornus canadensis	70	40	90	100
Lycopodium clavatum	70	60	60	90
Lycopodium obscurum	90	100	90	100
Pteridium aquilinum	50	50	40	90
Rubus pubescens	10	40	10	30

NOTE: Summer plants could not be identified at the time of the survey in November.

herbs, those which do; low shrubs, those that do not exceed 50 cm; and tall shrubs, those that grow over 50 cm.

Both density and biomass data were compared by analysis of variance. Because of nonhomogeneity of variances, the data were transformed with a natural log transformation before analysis. An F-test and the least significant difference (LSD) were used to compare means (Snedecor and Cochran 1967).

These analyses were based on the assumption that all areas had similar understory vegetation prior to logging. A survey begun before harvesting showed that all sites were similar for both species presence and frequencies (Table 1). Similarity indexes, based on frequencies and calculated using Ellenberg's formula (Mueller-Dombois and Ellenberg 1974), were all 96% or greater. Because the original investigators were mainly interested in shrub species, the survey was done in the late fall. The summer green species were no longer present then, but the major ones, sarsaparilla (*Aralia nudicaulis*,[5] aster (*Aster macrophyllus*), clintonia (*Clintonia borealis*), false lily (*Maianthemum canadense*), and starflower (*Trientalis borealis*) all reproduce primarily vegetatively. Examinations showed that individuals of these species found on plots the following growing season had originated from well-established underground parts. Thus, these species did exist on all sites before treatment.

Results

Composition

Species composition is one characteristic in which a change would be expected. During the first growing season there were differences between cut and uncut areas with quaking aspen, juneberry (*Amelanchier* spp.), bindweed (*Polygonum cilinode*), raspberry (*Rubus idaeus*), and strawberry (*Fragaria* spp.) occurring on harvested areas, but not on the uncut control. Anemone (*Anemone quinquefolia*) and twisted stalk (*Streptopus roseus*), however, were found only on the uncut control (Table 2). In winter versus spring full-tree harvest sites, paper birch and strawberry were restricted to the spring site; fireweed (*Epilobium angustifolium*), coltsfoot (*Petasites palmatus*), and twinflower (*Linnaea borealis*) to the winter site.

By the second growing season there were a large number of species differences between the harvested sites and the uncut control, with 23 species found on one or more of the logged areas, but not on the control (Table 2). Most of these species (19 of the 23) were tall herbs of which 7 were annual or biennial and 11 were perennials. Thirteen species found on the control were absent from one or more of the three clear-cut sites. The tree-length, burned site had the largest loss of 10 species, while the winter and spring full-tree sites lost 5 and 7 species, respectively. Thus, on the unburned sites most of the compositional changes were due to species invasions with few species disappearing.

Differences between cut areas increased the 2nd year on sites that were logged only; there were 21 species (mainly tall herbs) that did not occur on the unburned

[5]Plant nomenclature follows Fernald (1970) unless authority is given.

TABLE 2. Occurrence and density (stems per square metre) of understory species the first and second growing seasons after logging in northern Minnesota

Species	First season: Winter full-tree logging	First season: Spring full-tree logging	First season: Control	Second season: Winter full-tree logging	Second season: Spring full-tree logging	Second season: Winter tree-length logging and summer burn	Second season: Control
Ferns and fern allies							
Lycopodium clavatum	1.35*a*	0.15*a*	0.22*a*	0.22*a*	0.02*a*	0	3.22*b*
Lycopodium obscurum	1.57*a*	2.45*a*	5.93*b*	0.79*a*	0.26*a*	0.77*a*	5.60*b*
Pteridium aquilinum	0.78*a*	0.31*a*	0.16*a*	2.70*a*	0.53*b*	7.75*a*	0.15*b*
Subtotal	3.70*a*	2.91*a*	6.31*b*	3.71*a*	0.81*b*	8.52*a*	8.97*a*
Grasses							
Bromus tectorum	—	—	—	0	0.01	0	0
Carex spp.	—	—	—	0.58*a*	1.83*b*	5.45*c*	0
Oryzopsis spp.	—	—	—	0.54*a*	0.59*a*	0.01*b*	0.37*a*
Subtotal				1.12*a*	2.43*b*	5.46*c*	0.37*d*
Vines							
Convolvulus sepium	0	0	0	0	0.44*a*	38.57*b*	0
Polygonum cilinode	2.48*a*	0.34*b*	0	6.56*a*	2.85*b*	1.11*c*	0
Subtotal	2.48*a*	0.34*b*	0	6.56*a*	3.29*a*	39.68*b*	0
Low herbs							
Anemone quinquefolia	0	0	0.38	0	0.15*a*	0.10*a*	0.26*a*
Clintonia borealis	3.34*a*	1.19*b*	12.75*c*	1.83*a*	0.55*b*	0.32*b*	11.97*c*
Coptis groenlandica	1.41*a*	0.01*b*	0.01*b*	0.10*a*	0	0	7.76*a*
Cornus canadensis	18.20*a*	1.35*b*	12.08*a*	14.63*a*	0.85*b*	1.94*b*	11.37*a*
Fragaria spp.	0	0.94	0	0.98*a*	2.11*a*	0.05*b*	0.15*b*
Galium triflorum	1.52*a*	0.73*a*	0.68*a*	1.19*a*	0.63*a*	0.10*b*	0.09*b*
Maianthemum canadense	2.09*a*	2.71*a*	15.91*b*	0.37*a*	0.42*a*	1.04*a*	21.10*b*
Petasites palmatus	0.05*a*	0	0.30*a*	0	0	0	0.18
Pyrola secunda	0	0	0	0	0	0	0.46
Rubus pubescens	1.15*a*	1.19*a*	1.10*a*	0.54*a*	0.91*a*	0.11*a*	0.26*a*
Streptopus roseus	0	0	0.32	0	0.01*a*	0	0.20*a*
Trientalis borealis	0.43*a*	0.21*a*	2.38*b*	0.81*a*	0.20*b*	0	2.01*c*
Viola spp.	0.47*a*	0.17*a*	0.91*b*	0	0.02*a*	0.05*a*	0.38*b*
Subtotal	28.66*a*	8.50*b*	46.82*c*	20.45*a*	5.85*b*	3.71*b*	56.19*c*
Tall herbs: annuals and biennials							
Chamaesarcha grandiflora	0	0	0	0	0	0.65	0
Chenopodium album	0	0	0	0.14*a*	0.99*a*	0	0
Corydalis sempervirens	0	0	0	0	0	0.39	0
Erigeron spp.	0	0	0	0.07*a*	0.20*a*	0.10*a*	0
Geranium bicknellii	0	0	0	0	0.05*a*	0.90*a*	0
Lychis alba	0	0	0	0.25	0	0	0
Potentilla norvegica	0	0	0	0	0.38	0	0
Subtotal	0	0	0	0.46*a*	1.62*ab*	2.04*b*	0

TABLE 2. (*Concluded*)

	Treatment						
	First season			Second season			
Species	Winter full-tree logging	Spring full-tree logging	Control	Winter full-tree logging	Spring full-tree logging	Winter tree-length logging and summer burn	Control
Tall herbs: perennials							
Actea rubra	0	0	0	0.01	0	0	0
Apocynum androsaemifolium	0	0	0	0.12*a*	0.21*a*	0.28*a*	0
Aralia nudicaulis	1.61*a*	1.15*a*	3.04*b*	2.64*a*	1.94*a*	1.31*a*	3.77*b*
Aster macrophyllus	5.18*a*	4.61*a*	4.92*a*	9.08*a*	15.80*a*	11.86*a*	3.24*b*
Aster praealtus	0	0	0	0.95*a*	1.91*a*	0	0
Aster umbellatus	0	0	0	0.12	0	0	0
Cirsium arvense	0	0	0	0.12*a*	0.65*a*	0.04*a*	0
Cirsium vulgare	0	0	0	0	0.04	0	0
Epilobium angustifolium	0.37*a*	0	0.02*b*	0	0.01	0	0
Lactuca spp.	0	0	0	0.02*a*	0.01*a*	0	0
Prenanthes alba	0	0	0	0.02	0	0	0
Solidago spp.	0	0	0	0.05*a*	0	0.12*a*	0
Sonchas spp.	0	0	0	0	0.06	0	0
Subtotal	7.16*a*	5.76*a*	7.98*a*	13.13*a*	20.63*a*	13.61*b*	7.01*b*
Low shrubs							
Diervilla lonicera	4.13*a*	0.53*b*	0.59*b*	4.31*a*	1.82*a*	1.68*a*	0.67*b*
Linnaea borealis	0.52*a*	0	1.58*a*	0.11*a*	0	0	1.31*b*
Lonicera canadensis	0.10*a*	0.33*a*	1.04*b*	0.32*a*	0.11*a*	0	0.44*a*
Rubus idaeus	1.17*a*	0.06*b*	0	6.45*a*	2.78*a*	0.05*b*	0.01*b*
Vaccinium spp.	0.11*a*	0.02*a*	0.93*b*	0.98*a*	0	0.21*a*	0.27*a*
Subtotal	6.03*a*	0.94*b*	4.14*a*	12.17*a*	4.71*b*	1.94*c*	2.70*bc*
Tall shrubs and tree reproduction							
Abies balsamea	0.02*a*	0.02*a*	1.20*b*	0.02*a*	0	0	1.68*b*
Acer rubrum	1.49*a*	0.26*b*	2.09*a*	2.56*a*	0.12*a*	0.10*a*	3.46*b*
Acer spicatum	4.63*a*	0.98*a*	0.26*a*	1.52*a*	0.05*a*	0.42*a*	0.31a
Amelanchier spp.	0.02*a*	0.01*a*	0	0.05*a*	0	0	0.06*a*
Betula papyrifera	0	0.06*a*	0.07*a*	0.11*a*	0.07*a*	0.60*a*	0.11*a*
Corylus cornuta	10.64*a*	3.58*ab*	0.74*b*	6.74*a*	5.20*a*	0.28*b*	0.77*c*
Populus tremuloides	0.58*a*	2.42*b*	0	0.51*a*	2.63*b*	1.41*b*	0.02*a*
Prunus spp.	0	0	0	0.04*a*	0.57*a*	0	0
Subtotal	17.44*a*	7.34*a*	4.29*a*	11.55*a*	8.64*a*	2.81*b*	6.41*a*
Total herbaceous	42.00*a*	17.51*b*	61.11*c*	45.43*a*	34.63*a*	73.02*b*	72.54*b*
Total woody	23.47*a*	8.28*b*	8.43*b*	23.72*a*	13.35*b*	4.75*c*	9.11*b*

NOTE: Means within a row for a season not followed by the same letter are significantly different at the 0.05 level.

area. Ten species growing on the winter full-tree harvested site were not on the spring full-tree area, and 10 species on the spring full-tree site were not found on the winter treatment site.

Density

A number of significant differences in density developed after only one growing season. Harvesting created conditions which stimulated the growth of quaking aspen, bindweed, and raspberry (Table 2). The cutting treatments, however, mainly created conditions detrimental to the prelogging plant communities. The density of clintonia ground pine (*Lycopodium obscurum*), false lily, violet (*Viola* spp.), blueberry (*Vaccinium* spp.), starflower, fly honeysuckle (*Lonicera canadensis*), and balsam fir was significantly lower on harvested sites.

Viewing the understory species by physiognomic classes reveals that harvesting created niches exploitable by vines, which were not present before cutting. The differences in density previously noted occurred mainly in the fern allies and low herbs. The decline of low herbs caused a decrease in overall herb density on both winter and spring full-tree sites, especially the latter. Woody stems increased on winter full-tree sites while the spring full-tree area had fewer low shrubs than the control.

As expected, density differences had increased by the second growing season. Two species that showed no response the first season, big-leaf aster and sedges (*Carex* spp.), increased on all cut areas the second season (Table 2). Density of bindweed and bush honeysuckle (*Diervilla lonicera*) was higher on all harvested areas, but especially on the winter full-tree site. Balsam fir essentially disappeared and ground pine and false lily became more scarce on cut areas. Starflower and clintonia did not decline any further, but remained at a density significantly less than on the control. Running clubmoss (*Lycopodium clavatum*) decreased drastically on treated sites, disappearing from the burned area.

The density of hazel (*Corylus cornuta*) on the winter full-tree site declined appreciably during the second year, but still remained higher than on the control. Raspberry, however, continued to increase and bracken fern (*Pteridium aquilinum*) and strawberry appeared in greater numbers than on the control. On the spring full-tree site, quaking aspen remained at 1st-year levels, raspberry increased even more, while bunchberry (*Cornus canadensis*) continued to decline. Hazel, strawberry, and morning glory (*Convolvulus sepium*) showed an increase over the control the second season. The most prominent characteristic of the burned area was an overwhelming density of morning glory. Quaking aspen and bracken fern were also at higher levels than on the control, while hazel and bunchberry were lower.

During the second season, low herbs declined even more on treated areas while vines continued to increase. Grasses also increased on cut areas, and annual and biennial tall herbs made their appearance. Comparing cutting treatments, winter full-tree logging resulted in more low herbs, low shrubs, and significantly more total woody vegetation. Low shrubs, tall shrubs, and tree reproduction were fewest on the burned area. Total herbs separated the areas into two groups with the full-tree sites having about half as many as the burned or control area (Table 2).

Based on their density changes, the species on each of the harvested areas were classed as invaders, increasers, decreasers, or neutrals. The invaders were species previously not present on the site but which were able to occupy and proliferate in niches created by the disturbance. They included bindweed, morning glory, and sedges. The increasers were species found on the areas before the harvest and which were able to take advantage of the changes that occurred. These included hazel, quaking aspen, raspberry, bush honeysuckle, asters, and strawberry. The neutrals and decreasers were also present before logging; after harvesting the neutrals remained fairly stable and the decreasers declined. Prominent among the neutrals were mountain maple (*Acer spicatum*), dwarf raspberry (*Rubus pubescens*), and fly honeysuckle, while balsam fir, clintonia, false lily, running clubmoss, and ground pine were decreasers.

Biomass

When the total aboveground biomass was compared between treated and control sites, it was evident that there was a large increase in understory production. At the end of the first growing season the logged areas had already produced an aboveground biomass equal to the understory standing crop of the control (Table 3). The area that was full-tree logged in the spring, however, had significantly less biomass than the area that was full-tree logged in winter. This was primarily due to lower production by herbaceous species.

By the second growing season, the increased annual understory production on logged sites was very evident. Between the end of the first and the second growing season, the understory biomass on the control had not changed significantly, 727 kg/ha versus 943 kg/ha. However, biomass on all treated areas increased substantially and was significantly greater than on the control site.

After two growing seasons only sarsaparilla had less biomass than the control on all clear-cut areas (Table 4). The spring full-tree logged area showed a large increase in big-leaf aster biomass. The full-tree logged sites contained more hazel biomass than either the burned or control area, with 948 and 293 kg/ha on the winter and spring full-tree sites, and 3 and 16 kg/ha on the burned

TABLE 3. Aboveground biomass (kilograms per hectare) of herbaceous and woody understory vegetation the first and second growing seasons after logging in northern Minnesota

	Treatment			
Component	Winter full-tree logging	Spring full-tree logging	Winter tree-length logging and summer burn	Control
		First season		
Herbaceous	593*a* (116)	278*b* (113)	—	429*ab* (87)
Woody	566*a* (229)	350*a* (120)	—	299*a* (115)
Total	1159*a* (233)	628*b* (166)	—	728*ab* (112)
		Second season		
Herbaceous	1579*a* (214)	2359*a* (531)	2081*a* (239)	622*b* (85)
Woody	2268*a* (707)	2157*ab* (961)	523*b* (298)	320*b* (108)
Total	3847*a* (718)	4516*a* (829)	2604*a* (352)	942*b* (135)

NOTE: Values given are the means with SE in parentheses, $n = 10$. Means within a row not followed by the same letter are significantly different at the 0.05 level.

and control sites, respectively. Biomass of grasses and vines was greater on cut areas than the control, while only the control had an appreciable amount of biomass in low herbs. The winter full-tree site had more low shrub biomass than any other treatment.

Discussion

Some of the differences in understory species composition among sites are probably not due solely to treatment effects. Other factors such as available seed may have influenced the community compositions. However, treatment was a major factor because it influenced the seedbed and the microclimate, and therefore largely determined the success or failure of the invading species.

Snow cover was an important factor in density changes on full-tree areas. The protective value of snow was demonstrated by the significant decline in low herb density on the spring full-tree site, which lacked a snow cover during logging. Of course, the susceptibility to damage of low herbs in the understory may also change with the season. Still, if the resource manager were interested in minimizing damages to this segment of the understory, an adequate snow cover during harvesting should be beneficial.

Prescribed burning appears to be the principle cause of differences in understory density on the tree-length logging area. The decline of hazel, the increase in bracken fern, and the appearance of morning glory, sedges, and squirrel corn (*Corydalis sempervirens*) were all likely due to the fire. Buckman (1964) demonstrated the use of prescribed burning to reduce the density of hazel. An increase of bracken fern following disturbances, and the invasion of burned areas by squirrel corn and sedges have been reported by Ahlgren (1960, 1974). The overwhelming domination of morning glory on the tree-length logged site, and its virtual nonexistence on other areas, indicates that the response was strongly related to the burning.

Classification of species into response classes is a useful concept. With a sufficient data base it should be possible to develop a model for predicting species response, based on the type of disturbance that occurred. For example, past work has shown that big-leaf aster increases after fire (Krefting and Ahlgren 1974), as it did in this study. However, species response depends on the severity of disturbance as well as the type. This is especially true for burned sites, but also holds for clear-cut areas as shown by the difference between the two full-tree sites. Even so, some species do respond consistently over a broad range of disturbance intensities. The most notable of these in the boreal forest region are the invaders. Seven of them (geranium (*Geranium bicknellii*), bindweed, fireweed, squirrel corn, sedges, goldenrod (*Solidago* spp.), and cherry (*Prunus* spp.)) have previously been shown to be invaders after fire (Ahlgren 1960, 1974; Krefting and Ahlgren 1974; Methven 1973).

Following cutting of the overstory, the understory has an increase in primary production and therefore standing crop biomass (Blair and Brunett 1976; Crawford 1976; Sidhu 1973). After fire there is also a rapid revegetation of sites (Ahlgren 1974), and a subsequent increase in production by the understory (Dyrness 1973). All three of the clear-cut areas followed these patterns with a substantial increase in biomass. Interestingly, hazel increased on the full-tree logged areas while it exhibited no change on the tree-length logged and burned site. Since this species often forms a relatively enduring seral stage, this study indicates that the resource manager can either favor or discourage this depending on the harvesting method chosen.

Compared with the uncut control site, the tree-length logged and burned treatment showed no increase in woody species in the understory, but the full-tree logging systems stimulated their reproduction and growth. Winter full-tree logging resulted in more increase in woody species than did the full-tree logging in the spring. Thus, for control of competition from woody species, often a problem on areas being regenerated to conifers in the Lake States, the tree-length harvest system with slash disposal by burning was more effective than the full-tree logging methods. The resource

TABLE 4. Aboveground biomass (kilograms per hectare) of major understory species the second growing season after logging in northern Minnesota

Species	Treatment			
	Winter full-tree logging	Spring full-tree logging	Winter tree-length logging and summer burn	Control
Ferns and fern allies				
Lycopodium obscurum	—	—	—	375
Pteridium aquilinum	197*a*	90*a*	563*a*	—
Total	197*a*	90*a*	563*a*	375*a*
Grasses				
Carex spp.	63*a*	174*a*	232*a*	—
Oryzopsis spp.	21	—	—	—
Total	84*a*	174*a*	232*a*	—
Vines				
Convolvulus sepium	—	—	473	—
Polygonum cilinode	474*a*	120*ab*	88*b*	—
Total	474*ab*	120*a*	561*b*	—
Low herbs				
Clintonia borealis	—	—	—	58
Cornus canadensis	—	—	—	62
Fragaria spp.	—	204	—	—
Maianthemum canadense	—	—	—	21
Trientalis borealis	—	—	—	1
Total	—	204*a*	—	142*a*
Tall herbs				
Aralia nudicaulis	22*a*	27*a*	8*a*	61*b*
Aster macrophyllus	536*ab*	1560*a*	601*ab*	23*b*
Total	558*a*	1587*a*	609*a*	84*a*
Low shrubs				
Diervilla lonicera	84*a*	—	5*a*	13*a*
Rubus idaeus	205*a*	33*b*	—	—
Vaccinium spp.	—	—	—	17
Total	289*a*	33*b*	5*b*	30*b*
Tall shrubs and tree reproduction				
Abies balsamea	—	—	—	12
Acer rubrum	228*a*	—	—	71*a*
Acer spicatum	—	—	—	166
Amelanchier spp.	1	—	—	—
Betula papyrifera	256*a*	—	204*a*	—
Corylus cornuta	948*a*	293*a*	3*b*	16*b*
Populus tremuloides	507*a*	1821*a*	311*a*	—
Prunus spp.	30*a*	5*a*	—	—
Total	1970*a*	2119*a*	518*a*	265*a*

NOTE: Means within a row not followed by the same letter are significantly different at the 0.05 level.

manager could also use the burn treatment to temporarily create pattern diversity since it did result in a dissimilar understory.

Following the harvest operations, the ecosystems had an initial stage of readjustment in which changes within the understory were relatively minor. By the second season, however, species, density, composition, and biomass had all changed significantly. However, most species that made up the former plant community were still present. Other studies have shown that the rate of change becomes slower; the initial invaders gradually disappear, early increasers decline, while the decreasers gain in importance (Corns and LaRoi 1976; Crawford 1976; Dyrness 1973; Lyon 1966). These changes are dependent upon the establishment of new overstory strata, and will progress as a function of increasing crown closure and the subsequent microclimatic changes which accompany this process. Thus, successional trends within these understories will continue, with species gaining or losing in community importance at various stages according to their place within the scheme. Even though some of the stages will vary, all sites should progress toward a similar understory community.

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